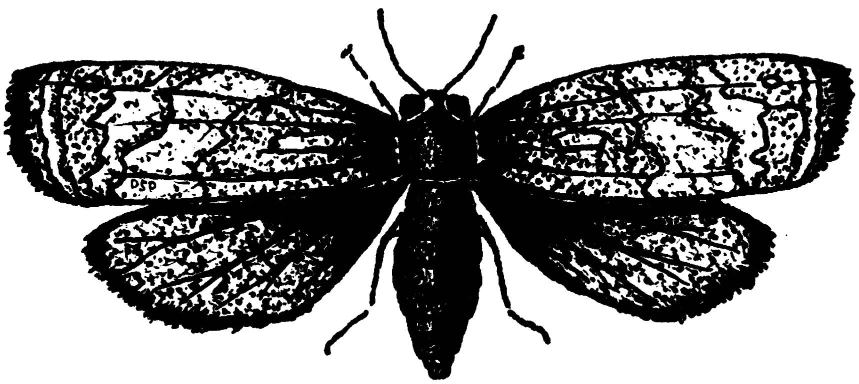
WESTERN SPRUCE BUDWORM



1976 LOSS ASSESSMENT SURVEY

NORTH-CENTRAL WASHINGTON

Forest Insect & Disease Management
S & PF Region Six

1976 WESTERN SPRUCE BUDWORM LOSS ASSESSMENT SURVEY
NORTH-CENTRAL WASHINGTON

by

T. Gregg, J. Wortendyke, D. Twardus, and J. Wear

October, 1979

ACKNOWLEDGEMENTS

The authors wish to acknowledge the assistance of Robert Young, Biometrician, Washington Office, Forest Insect and Disease Management, Methods Application Group, for his assistance in the design and analysis of this survey. In addition, the assistance of Rick Johnsey, Entomologist, Washington Department of Natural Resources, John Hazard, Biometrician, Pacific Northwest Forest and Range Experiment Station, and personnel of the Okanogan and Wenatchee National Forests for their assistance in conducting this survey.

INTRODUCTION

The current western spruce budworm, *Choristoneura occidentalis* Freeman, outbreak on the Okanogan and Wenatchee National Forests in north-central Washington was first recorded during the summer of 1970. The infestation increased in size until nearly 500,000 acres of defoliation occurred during 1974. In the most severely defoliated areas, top-killing and tree mortality apparently caused by defoliation were observed.

By the summer of 1975, the budworm population had continued to increase in these areas to a level that justified chemical control (USDA, Environmental Statement, 1976). In conjunction with the proposed chemical control project of 1976, a survey was planned to evaluate the effect on the timber resource of repeated budworm defoliation over large areas. The survey was conducted in cooperation with the Washington State Department of Natural Resources during July of 1976 on the Okanogan and Wenatchee National Forests.

It was anticipated that information gained from a survey of this nature would be useful in evaluating the long-term effects of budworm defoliation upon forest areas, in evaluating the need for future chemical and biological control, and in understanding the management implications of continued budworm defoliation.

OBJECTIVES

The survey included two broad objectives:

1. To estimate changes in relative tree growth, incidence of top-kill and tree mortality, changes in per acre tree volumes, and understory stocking in areas defoliated by western spruce budworm.

2. To estimate the extent of long-term differences in tree volumes, growth rates, top-killing, tree mortality, and understory stocking between areas chemically treated for budworm control in 1976 and areas not treated. This objective would not be fulfilled until 5 years after chemical treatment (1981).

SURVEY DESIGN

This survey was based upon a stratified random sample of forest conditions within defoliated and non-defoliated areas of the Wenatchee and Okanogan National Forests. Initial stratification was determined by composite mapping of annual Forest Insect and Disease Management aerial surveys conducted during the summers of 1971 through 1976. These aerial survey maps were used to delineate forested areas that had been defoliated 2, 3, 4, and 5 consecutive years. No attempt was made to include severity of defoliation in the stratification. The survey maps were also used to delineate host-type areas where WSBW defoliation had not occurred. Table 1 describes the 5 resulting strata that were sampled.

Table 1.--Description of defoliation strata and number of plots sampled within each strata.

Strata	Strata Description	Total Acres	No. plots
0	No defoliation recorded	75,000	25
2	2 years of defoliation	228,770	30
3	3 years of defoliation	197,020	40
4	4 years of defoliation	133,640	43
5	5 years of defoliation	64,490	42

The 5 strata were additionally divided into those areas that would be chemically treated in 1976 and those not to be treated. This stratification was originally intended to satisfy objective 2 of the survey. Additional chemical treatment during 1977, however, jeopardized use of the original spray-unsprayed stratification. In 1981, the areas will be restratified based upon the 1977 spray boundaries, in order to satisfy objective 2.

It is important to note that the survey was based upon operational aerial sketchmapping procedures used by the U. S. Forest Service to delineate areas of budworm activity during 1971-1976. These sketchmaps were used in the present survey because they represented an operational tool that could be used in the evaluation of budworm outbreak over large areas. The results of this survey, then, should be interpreted only insofar as they relate to areas of budworm outbreak delineated by these aerial sketchmap procedures. Sketchmapped areas of defoliation are broad classifications and may contain a wide variety of individual tree defoliation within each strata.

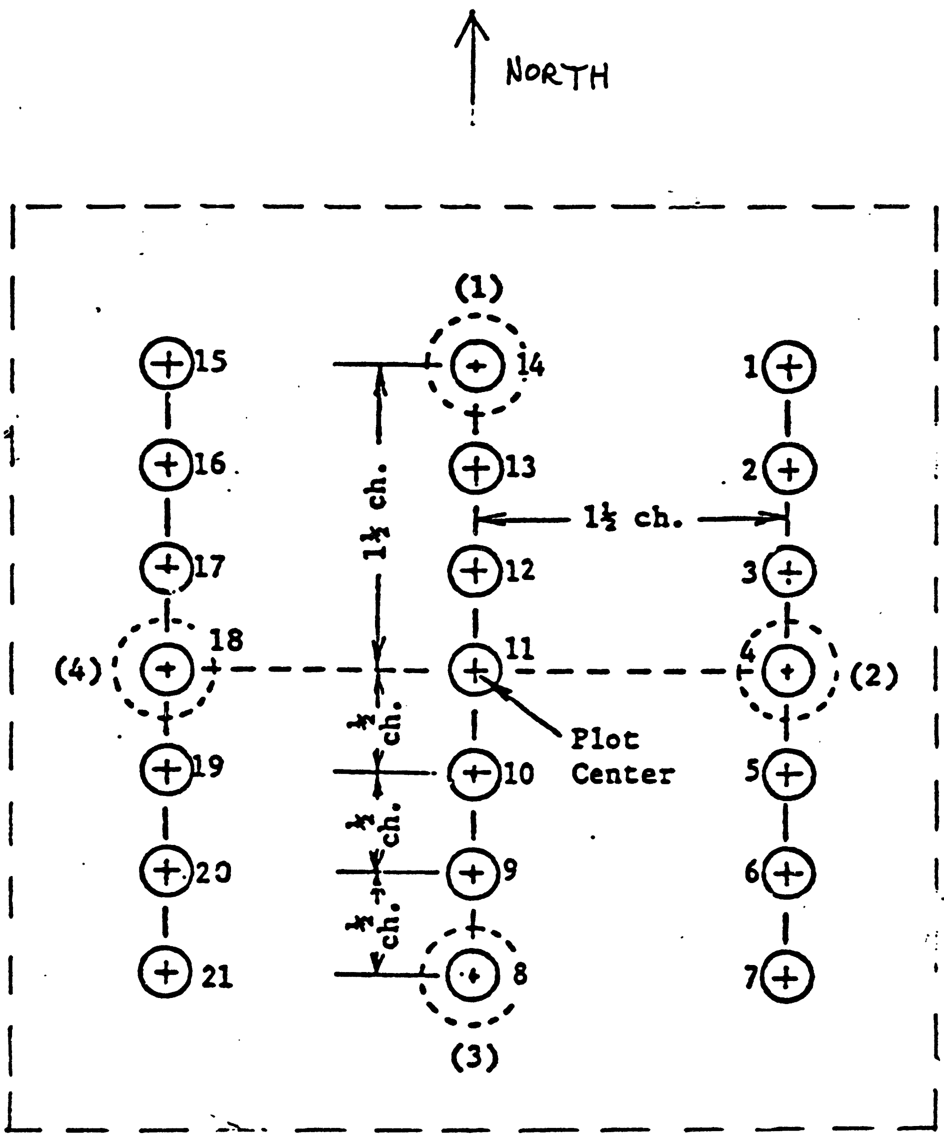
Within each of the 5 defoliation strata, data collection plots were randomly located by sequentially numbering all samplable quarter-sections within strata boundaries and then randomly selecting plot locations. Samplable quarter-sections were defined as those areas that were predominantly host-type and whose centers were, at least, one quarter mile from a strata boundary. Plot locations were recorded on 1:15,840 scale black and white resource photographs and established in the field as near as possible to center of the selected quarter-sections.

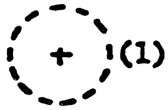
Each plot (primary sampling units) consisted of 2 sets of subplots (secondary sampling units) and covered an area of approximately 2 acres. The first set, hereafter referred to as the overstory subplots, consisted of 4 systematically

1/ Understory tree stocking subplots were not established in the non-defoliated strata.

established variable-sized subplots. The second set, hereafter referred to as understory subplots, consisted of 21 systematically established 1/200-acre circular subplots[1/]. Figure 1 illustrates the subsampling within each plot. Plot and overstory subplot centers were marked with metal pipes for future relocation.

Figure 1. Diagram of a typical plot (scale: 1 inch = 66 feet).





Volume subplot and subplot number (broken line to indicate variable-size resulting from prism cruise).

Understory subplot and subplot number (1/200-acre; radius = 8.33 feet).

2-acre area represented by plot.

OVERSTORY SUBPLOTS

Overstory subplots were systematically arranged within each 2-acre plot. Overstory subplot number 1 was placed 1½ chains due north of the plot center; subplot 2, 1½ chains due east; subplot 3, 1½ chains due south; and subplot 4, 1½ chains due west from a metal pipe marking plot center.

A 20 BAF angle gauge was used to eatablish the boundaries of each subplot. All trees with a DBH of 5.0 inches or greater within this prism point plot were considered as data trees. Trees estimated as having been dead for more than 5 years were excluded.

At each subplot, the following data were collected:

1. Tree species
2. Total tree height
3. Length of top-kill as evidenced by grey bark color
4. Crown class based upon Region 6 crown class definitions
5. Damage class as follows:

Class	Tree condition
0	Alive, no top-kill
1	Alive, top-kill caused by budworm
2	Dead, due to budworm defoliation
3	Alive, top-kill not caused by budworm
4	Dead, due to causes other than budworm defoliation, i.e., bark beetles, lightning, disease.

In addition to the above, one increment core was taken at DBH from each subplot conifer. These were sent to the Intermountain Forest Science Laboratory in Moscow, Idaho, for measurement of annual growth over a 20-year period to the nearest 1/100 millimeter.

UNDERSTORY SUBPLOTS

Understory subplots were spaced at 1/2 chain intervals along 3 lines, with 7 subplots on each line. The 2 outer lines (Figure 1) of subplots coincided with overstory subplots 2 and 4. The center line of understory subplots coincided with overstory subplots 1 and 3.

All coniferous regeneration (1-5") occurring on the 1/200 acre subplots were considered as potential crop trees contributing to the understory. Only trees judged as acceptable crop trees, however, were tallied. Each acceptable tree was tallied according to highest point occupancy.

Point occupancy was based upon the amount of growing space a tree is using. The tree that is considered to be occupying the greatest amount of growing space on the subplot was tree number 1, the tree occupying the next greatest

amount was tree number 2, etc. Trees on each subplot were examined and tallied by point occupancy ranking until 4 satisfactory crop trees or all potential crop trees (whichever was less) was recorded. Trees classed as unsatisfactory crop trees for reasons other than western spruce budworm were not tallied. Potential crop trees were determined based upon the criteria detailed on pages 42.2--10 through 42.2--16 of the Silvicultural Examination and Prescription Handbook (FSH 2409.26d R6). Only those trees judged acceptable as crop trees regardless of the effect of the western spruce budworm were tallied. Trees were classed as (1) satisfactory if the spruce budworm had not caused them to become unacceptable crop trees, and (2) unsatisfactory if the budworm had caused them to become unacceptable. The following data were recorded for each subplot:

1. Species Code (same as for volume subplots)
2. DBH to the nearest inch
3. Stocking class according to the following classification system:

Class	Tree Condition (in terms of satisfaction for stocking)
0	Nonstocked subplot
1	Satisfactory tree
2	Unsatisfactory tree, western spruce budworm the primary cause

DATA ANALYSIS

The data were analyzed to determine the effect of budworm defoliation over the entire outbreak area in north-central Washington. Defoliation strata were used as a sampling scheme for plot allocation. Data collected from all plots within each strata could be extrapolated for the entire strata. Combining all strata would then provide information for the outbreak as a whole (1971-1976).

Understory

Three categories were used to evaluate defoliation effects upon the understory: (1) percent of area adequately stocked, (2) mean diameter of potential crop trees, and (3) number of potential crop trees per acre. The data were analyzed to reflect understory structure both as it was and as it would have been in the absence of budworm defoliation. Changes in area stocking were evaluated on the basis of subplots considered not stocked due to budworm defoliation. Changes in understory average diameters were analyzed by comparing the mean diameters of all understory crop trees including those damaged or killed by budworm, with the mean diameters of only acceptable or undamaged crop trees. In addition, the average number of trees per acre before and after budworm defoliation was evaluated by subtracting trees killed or damaged by budworm from the tree tally and comparing this with the total number present.

Overstory

The effect of budworm defoliation upon the overstory was analyzed in terms of tree radial growth, tree volumes, tree mortality, and top-killing. Data were compiled using "VPLOT," a computer program designed by the senior author to compile variable plot stand data and compute numbers of trees and volumes per acre by diameter class. All overstory plot trees were grouped according to Douglas-fir, true fir, and other coniferous species.

Growth loss and volumes per acre were calculated first on an individual tree basis. Growth loss was defined as the difference between actual radial growth during the outbreak years (1971-1976) for defoliated trees and the predicted radial growth in the absence of defoliation. The objective of the analysis was to use radial growth of nondefoliated host trees as the basis for predicting growth of defoliated trees for the outbreak years. Analysis of covariance and linear regression procedures were used to accomplish this. Details of this analysis are outlined in the Appendix.

The regression coefficients resulting from the nondefoliated tree growth data were used by species group to recalculate the 5-year radial increment (1972-1976) for individual trees in the defoliated strata. This resulted in new or predicted diameters being assigned to defoliated trees.

Height-diameter relationships by species group were developed for all overstory plot trees in the nondefoliated strata. The equations developed are listed in the Appendix. These height-diameter equations were used to calculate new heights of defoliated trees based upon the new or predicted diameters. The predicted heights and diameters of defoliated trees were then used to calculate tree volumes for comparison to existing tree volumes in the defoliated strata. Volumes were calculated using Bruce's Taper Formula.

"VPLOT" was used to generate stand tables for existing volumes per acre, predicted volumes per acre, and the difference or volume loss per acre. Incidence of mortality and top-killing resulting from budworm defoliation was expressed in terms of trees per acre by diameter class. Volume per acre of trees killed by budworm was also calculated.

RESULTS AND DISCUSSIONS

Baseline Data

As illustrated in Table 2 and Figures 2-3, the nondefoliated stratum and the defoliated strata were similar in terms of trees per acre and average basal area per acre of budworm-susceptible trees. Defoliation stratum 5 does, however, have a greater ratio of host to non-host basal area per acre than exists in the other strata. When ranked in order of the strata with the greatest amount of host basal area per acre in relation to non-host basal area per acre, the strata would appear: Strata 5 (5.2:1); Strata 0 (3.0:1); Strata 2 (1.9:1); Strata 3 (2.9:1); and Strata 4 (1.7:1). This illustrates that host basal area may not be important in determining whether or not an area is susceptible to budworm outbreak. For example, the non-defoliated strata has more host basal area per acre present than 3 of the defoliated strata.

Table 2.--Average basal area per acre (sq.ft.) by defoliation strata and tree species.

Species group	Defoliation strata				
	0	2	3	4	5
Douglas-fir	66.0 (10.8)1/	62.0 (6.9)	52.9 (7.0)	51.3 (4.4)	73.3 (7.3)
True fir	20.2 (7.1)	12.8 (3.3)	37.7 (6.6)	22.3 (4.3)	28.7 (5.4)
Ponderosa pine	21.8 (4.8)	15.0 (4.0)	10.6 (2.8)	9.0 (2.4)	10.6 (2.4)
Other conifer	6.8 (4.3)	23.2 (8.0)	20.0 (4.2)	33.7 (8.0)	8.9 (2.2)
% BA, All host	75.1	66.2	74.7	63.3	83.9
% BA, Non-host	24.9	33.8	25.2	36.7	16.0

1/ Numbers in parentheses are standard errors.

Figures 2 and 3 show the diameter distribution of both host and non-host trees within the defoliated and non-defoliated strata. Diameter distributions are apparently uniform throughout strata, with the 2-10" class being most prevalent in all strata.

Figure 2.--Diameter distribution of host trees within non-defoliated and defoliated stands

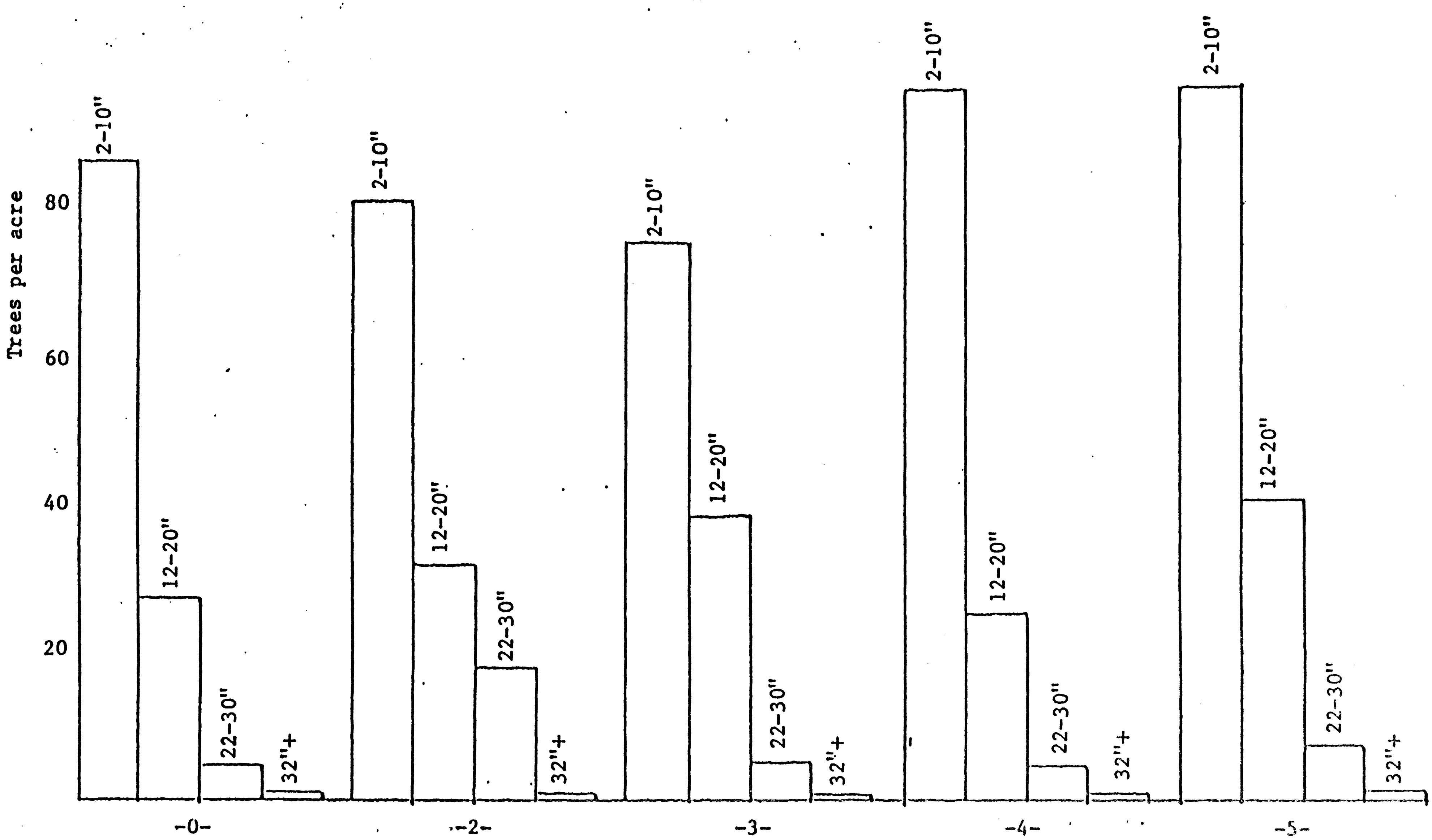
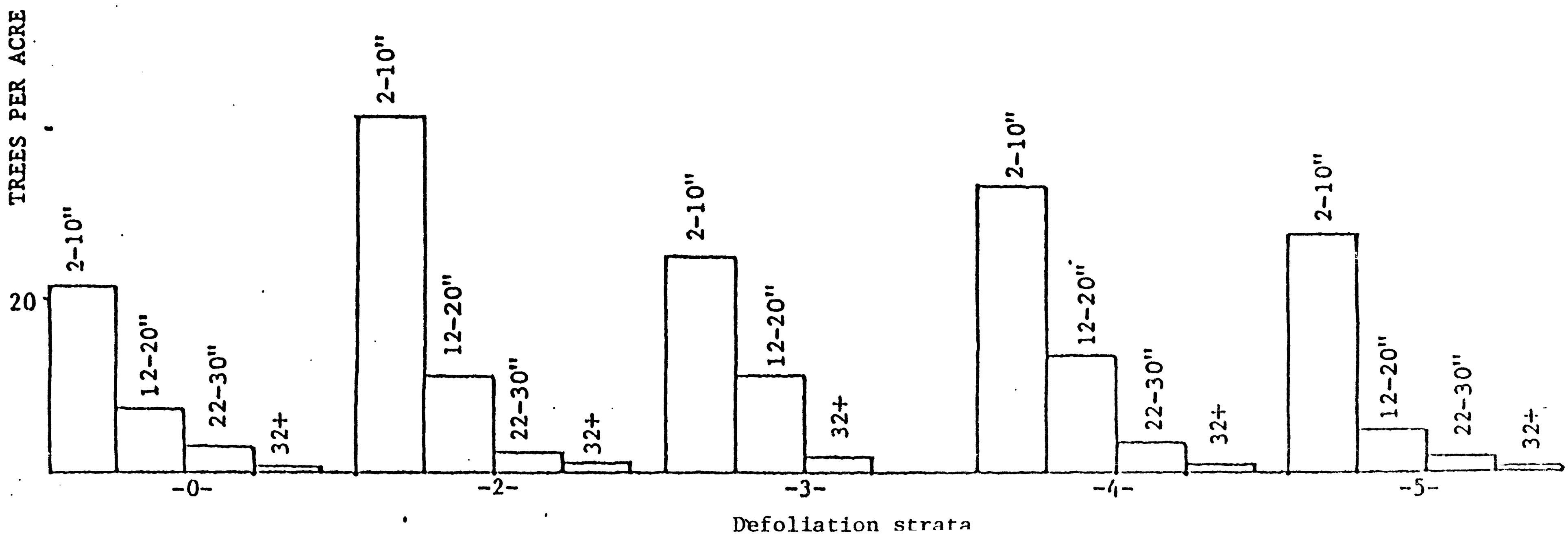


Figure 3.--Diameter distribution of non-host trees within defoliated and non-defoliated strata



Effects of Defoliation Upon the Understory

Table 3 illustrates the effect of budworm defoliation upon understory stocking levels. Percent of stratum stocked in all of the defoliated strata (understory measurements were not collected in the non-defoliated stratum) averaged 58% before budworm damage took place. After budworm damage was accounted for, percent of stratum stocked averaged 53%. It is apparent from the data in Table 3 that damage to understory stocking is progressive by years of budworm defoliation.

Understory subplots frequently had more potential crop trees than the minimum number required by Region 6 standards to be classed as a stocked subplot. This included true firs, Douglas-firs, and other conifer species present. Often budworm-susceptible trees having a high site occupancy rating were so severely damaged by budworms as to no longer be suitable as potential crop trees. Remaining non-host species, however, would still result in the subplot being considered stocked. The overall effect of this, as seen in Table 4, is to reduce the number of potential crop trees per acre to a greater extent than the reduction in stocking levels. In a sense, one of the effects of budworm defoliation upon the understory may be to alter the species composition favoring non-susceptible species. When the number of future crop trees lost to budworm damage are expressed as a percent of the total number present before budworm damage, this damage accounts for an average of a 14% loss in numbers of trees. Strata 5, with a 25% loss in crop trees per acre, accounts for the greatest amount of damage in the understory. As seen in Table 4, diameter measurements show a shift towards increasing average residual diameters of potential crop trees. This is most likely attributed to the effects of defoliation being more prevalent on smaller-diameter host trees. In an area, such as stratum 5, with budworm defoliation for a period of years, many of the budworm-susceptible crop trees are destroyed while remaining non-host crop trees have less competition and hence greater average diameters per acre.

Table 3.--Effect of WSBW defoliation upon understory stocking levels

Data category	Subplot means strata (Years of defoliation)			
	2	3	4	5
Percent of stratum stocked before budworm defoliation	54.13(5.13) 1/	60.36(3.74)	63.46(3.23)	53.06(3.54)
Percent of stratum stocked after budworm defoliation	50.32(4.71)	57.26(3.96)	58.92(3.35)	46.15(3.71)
% stocking loss	3.81(2.25)	3.10(1.00)	4.54(1.25)	6.91(1.63)

1/ numbers in parentheses are standard errors.

Table 4.--Effects of WSBW defoliation upon understory crop trees per acre and average crop tree diameters.

Data category	Subplot means strata (Years of defoliation) 2	3	4	5
Number of potential crop trees per acre before budworm outbreak	255.27(33.61)[1/]	286.40(24.46)	293.02(18.83)	244.00(30.49)
Number of potential crop trees per acre after budworm outbreak	220.30(28.78)	264.53(24.85)	257.59(17.49)	183.91(18.18)
Number of potential crop trees per acre lost due to budworm damage	34.97(19.63)	21.87(6.27)	35.43(10.32)	60.09(21.12)
Ave. diameter (in.) of understory crop trees before budworm damage	3.82(.40)	3.21(1.39)	3.15(1.52)	3.95(1.85)
Ave. diameter (in.) of understory crop trees after budworm damage	3.93(.40)	3.39(.24)	3.34(.24)	4.31(.31)
Percent change in average crop tree diameter	(+)2.70%	(+)5.55%	(+)6.19%	(+)9.16%

1/ numbers in parentheses are standard errors

Effects of SBW Defoliation Upon the Overstory

Top-killing and tree mortality are the most noticeable effects of continuous budworm outbreaks. Tables 5 through 10 illustrate the amount of budworm-related top-killing and tree mortality for Douglas-fir and true firs. In general, the effects of the outbreak upon the true firs appear to be greater than for Douglas-fir. This result supports investigations by Williams (1966) and Carolin (1975).

One interesting result of the analysis is the large numbers of trees, in all of the defoliated strata, with top-killing and tree mortality due to causes other than spruce budworm. In many cases, more non-spruce budworm caused top-killing and mortality was evident than top-killing and mortality due to budworm. Similar results were reported by Bousfield (1979). Some of these effects may have been due to previous budworm defoliation, while others due to lightning, bark beetles, and disease.

As illustrated in Table 9, and the diameter distribution shown in Figures 2 and 3, budworm-caused top-killing and mortality appears to occur in those diameter classes (2-20") most common within the forest. It is important to note, however, that both tree mortality and top-killing due to budworm do not occur uniformly across outbreak strata. For all defoliated strata combined, top-killing was clustered in 34% of the plots and tree mortality in 9% (Table 10). This illustrates the variation that can occur within a budworm outbreak. The survey indicates that averaged over the entire area, budworm-caused top-killing would occur in 8.8% of the Douglas-fir per acre, and 15.8% of the true firs per acre. On an individual plot basis, top-killing averaged from zero to over 65% of the Douglas-fir per acre. For true firs, it ranged from zero to 100% per acre.

A similar situation exists for budworm-caused mortality. Tree mortality occurred in very localized areas and not necessarily more frequent in strata 5 than other strata. In most cases, however, significant mortality, in comparison to non-budworm-caused mortality, was greatest in strata 5. For individual plots, mortality due to budworm ranged in Douglas-fir from 0 to nearly 180 cu. ft. per acre, while in true fir mortality ranged from 0 to nearly 150 cu. ft. per acre. As shown in Tables 7 and 8, when mortality is averaged over each strata, cubic foot loss per acre appears considerably less.

Tree mortality caused by budworm defoliation, when averaged over a large area, appears to be one of least significant effects even after 5 years of defoliation. When averaged over all strata, tree mortality amounts to about 1% of the true fir per acre, and about .4% of the Douglas-fir per acre. For both true fir and Douglas-fir, however, there is a marked increase in tree mortality after 5 years of defoliation as compared to the other defoliated strata (Tables 5, 6).

For all host trees, WSBW-caused mortality expressed as a percent of the host trees per acre is 7-fold greater in strata 5 than in stratas 2, 3, and 4 combined. Much of this increase is accounted for by increased mortality in true fir after 4 years of budworm infestation. Increase in top-killing is not as

pronounced. Top-killing for host trees increases almost 1.5-fold in stratum 5 in comparison to stratas 2, 3, and 4 combined. Actually, for Douglas-fir and true fir, more top-killing occurs in stratum 3 than any other strata. This may be due to more intense defoliation within this stratum than within other strata.

Overall, the data appears to indicate that the effects of defoliation become most prevalent after 5 years of infestation and, in fact, losses in timber resources may not become significant until at least this time. As an outbreak continues after 5 years, timber losses may accumulate at a greater rate than observed here.

Table 5.--Top-killing and tree mortality in Douglas-fir caused by 2, 3, 4, and 5 years of budworm defoliation.

	Defoliation strata				
	0	2	3	4	5
Number of trees/AC w/top-kill caused by SBW	0	1.6 (.888) 1/	7.6 (2.807)	5.7 (2.952)	9.0 (2.410)
Number of trees/AC w/top-kill not caused by SBW	.6 (.405)	7.5 (3.009)	5.1 (1.843)	5.6 (2.116)	7.8 (1.915)
Number of SBW top-kills as % of total DF trees/AC present	0%	2%	14.3%	8.4%	10.5%
Number of SBW-caused dead trees per acre	0	.1 (.119)	.1 (.090)	.1 (.093)	1.1 (.553)
Number of non-SBW-caused dead trees per acre	0	.2 (.212)	0	.2 (.213)	.5 (.305)
Number of SBW-caused dead trees as % of total DF trees/AC	0%	.1%	.2%	.1%	1.3%

1/ numbers in parentheses are standard errors of the means

Table 6.--Top-killing and tree mortality in True fir caused by 2, 3, 4, and 5 years of budworm defoliation.

	Defoliation strata				
	0	2	3	4	5
Number of trees/AC w/top-kill caused by SBW	0	1.6 (1.345)1/	15.4 (5.497)	7.6 (3.159)	11.8 (3.518)
Number of trees/AC w/top-kill not caused by SBW	.6	.4 (.308)	2.5 (1.227)	2.4 (.924)	3.0 (1.117)
Number of SBW top-kills as % of total true fir trees per acre	0%	1.3%	24.7%	14.0%	21.9%
Number of SBW-caused dead trees per acre	0	.2 (.212)	.2 (.159)	.2 (.213)	1.6 (.868)
Number of non-SBW-caused dead trees per acre	0	.3 (.306)	.4 (.247)	.4 (.334)	0
Number of SBW-caused dead trees as % of total true fir trees per acre	0%	.7%	.3%	.4%	3.0%

1/ numbers in parentheses are standard errors of the means

Table 7.--Douglas-fir mortality (cu.ft. per acre) related to spruce budworm defoliation.

	Defoliation strata				
	0	2	3	4	5
Vol. per acre dead, SBW-caused	0	4.6 (5.0)	4.0 (4.0)	7.7 (5.0)	15.8 (9.0)
Vol. per acre dead, not SBW-caused	8.1 (8.0)	4.8 (5.0)	0	2.5 (2.0)	16.3 (8.0)
Predicted vol. per acre	2162.5 (416)	2001.6 (257)	1781.7 (258)	1700.9 (155)	2391.9 (260)
SBW-caused mortality as % of predicted volume per acre	0	.2%	.2%	.5%	.7%

Table 8.--True fir mortality (cu.ft. per acre) related to spruce budworm defoliation.

	Defoliation strata				
	0	2	3	4	5
Vol. per acre dead, SBW-caused	0	3.9 (4.0)	2.9 (3.0)	3.4 (3.0)	29.8 (17.0)
Vol. per acre dead, not SBW-caused	0	3.5 (3.0)	9.6 (5.0)	14.6 (12.0)	0
Predicted vol. per acre	662.8 (245)	379.5 (100)	1125.3 (209)	606.0 (119)	869.3 (167.0)
SBW-caused mortality as % of predicted volume per acre	0	1.0%	.3%	.6%	3.4%

Table 9.--Average number of trees per acre with top-killing in Douglas-fir and true fir by diameter class.

Diameter class (in.)	Defoliation strata 0	2	3	4	5
2-10	0	1.3	15.0	10.0	12.9
12-20	0	1.7	6.9	2.9	6.5
22-30	0	0	1.0	.4	1.4
32+	0	.2	.1	0	0
Total trees per acre	0	3.2	23.0	13.3	20.8

Table 10.--Distribution of budworm-caused top-killing and tree mortality by occurrence within plots.

Defoliation strata	Total No. plots	# plots with SBW top-kill	% of total no. plots	# plots with SBW tree mortality	% of total no. plots
2	30	6	20%	2	7%
3	40	17	43%	2	5%
4	43	13	30%	3	7%
5	42	19	45%	7	17%

The effect of budworm defoliation upon tree radial growth increment is illustrated in Table 11. Using increment cores taken at DBH, as this survey does, includes the errors associated with missing growth rings due to severe defoliation. For this reason, the radial growth loss associated with defoliation should be viewed as a conservative estimate. The actual statistical procedures used to generate these estimates are described in the Appendix. As illustrated in Table 11, growth rates remained relatively constant for host trees in the non-defoliated strata, while those in defoliated strata were decreased by as much as 22% for true fir after 5 years of defoliation history.

The growth of non-defoliated host trees was used as a comparison to the growth of defoliated host trees. One of the weaknesses inherent in this approach is that the non-defoliated trees are growing on different sites removed from the area of defoliation. The non-defoliated trees may have been growing on more favorable sites, which could explain their better growth and also the absence of any budworm defoliation in these areas.

Table 11.--Mean 5-year increments and growth increment ratios for host trees. Standard errors of the estimates appear in parentheses. 1972-1976 are the outbreak years.

Strata	72-76 Mean	72-76 S.E.	67-71 Mean	67-71 S.E.	Growth Ratio 67-71 / 72-76	% Reduction in mean annual incr. 67-71 to 72-76*
True Fir						
0	.527	.044	.524	.037	1.0:1	0.0
2	.474	.036	.521	.046	1.1:1	8.7
3	.451	.019	.518	.021	1.5:1	13.5
4	.428	.021	.479	.021	1.1:1	10.9
5	.434	.017	.561	.021	1.3:1	22.3
Douglas Fir						
Strata	Mean	S.E.	Mean	S.E.		
0	.534	.022	.549	.023	1.0:1	2.7
2	.377	.015	.422	.017	1.1:1	10.7
3	.467	.017	.515	.018	1.1:1	9.7
4	.394	.014	.448	.014	1.1:1	12.2
5	.373	.010	.467	.011	1.3:1	12.2

$$* \quad \frac{\left(\frac{\text{Mean Growth 67-71}}{5}\right) - \left(\frac{\text{Mean Growth 72-76}}{5}\right)}{\left(\frac{\text{Mean Growth 67-71}}{5}\right)} \times 100 = \text{\% reduction in mean annual increment}$$

Table 12 shows the radial growth loss expressed as a volume per acre loss. These volume per acre losses (host species only) represent the cumulative effects of varied amounts of budworm defoliation. For the particular budworm

Table 12.--Average growth volume lost per acre (cu.ft.) by defoliation strata and host species. Numbers in parentheses are standard errors of the means.

Data category	Defoliation strata 0	2	3	4	5
Douglas-fir					
Predicted vol. per acre	2162.5 (416)	2001.6 (257)	1781.7 (258)	1700.9 (155)	2391.9 (260)
Volume per acre loss due to WSBW	0	9.3 (1)	8.6 (1)	7.0 (1)	25.6 (2)
Loss as % of predicted volume	0%	.5%	.5%	.4%	1.0%
True fir					
Predicted vol. per acre	662.8 (245)	379.5 (100)	1125.3 (209)	606.0 (119)	869.3 (167)
Volume per acre loss due to WSBW	0	6 (2)	17 (3)	8.5 (2)	24.7 (4)
Loss as % of predicted volume	0%	1.6%	1.5%	1.4%	2.8%

outbreak which occurred in north-central Washington between 1971 and 1976, the volume per acre loss figures can be used as an estimate of budworm-related growth loss over the entire area. Table 13 shows the total volume per acre loss due to growth increment reduction over all of the defoliated strata. Unlike top-killing and tree mortality, the effects of defoliation upon tree growth were generally distributed over all plots. More severe defoliation in localized areas, however, did produce greater growth loss per acre in some areas than others.

Similar to tree mortality, growth loss shows a marked increase in stratum 5 in comparison to the other defoliated strata.

Table 13.--Total growth volume lost over spruce budworm outbreak area in north-central Washington, 1971-1976.

Strata	Acres	Total host growth vol. loss per acre (CF)	Total growth vol. loss over defoliated strata (CF)
Acreage with two years of recorded outbreak	228,770	15.3	3,500,181
Acreage with three years of recorded outbreak	197,020	25.6	5,043,712
Acreage with four years of recorded outbreak	133,640	15.5	2,071,420
Acreage with five years of recorded outbreak	64,490	50.3	3,243,847

Mortality (CF) per acre caused by SBW

As shown in Table 12, growth loss due to defoliation when expressed as a percent of the volume per acre expected without defoliation ranges from .4% for Douglas-fir to 2.8% for true firs. Though these amounts are not too significant, it should be remembered from Table 11 that the growth rates have decreased by 12 and 22%, respectively, after 5 years of defoliation. In all cases, true fir appears to suffer greater growth loss due to defoliation than Douglas-fir. When growth loss is expressed as a yearly loss for all host species, the average loss for all strata combined is 26.68 cu. ft. per acre per year. Bousfield (1979) working in Idaho reports growth loss ranging from 10.8 to 46.7 board feet per acre per year for areas with budworm outbreak for 6 years. In the present survey, areas with 5 years of budworm activity show a loss of 10.06 cu. ft. per acre per year. This compares with an estimated 50 cubic feet per acre per year growth on average Douglas-fir and true fir sites in north-central Washington (Personal Communication, Gero Mitchelson, Silviculturist, Okanogan NF). This estimated 20% reduction in volume per acre per year would compare with the 17% reduction in growth rate for true fir and Douglas-fir combined for Strata 5 of Table 11.

The cumulative volume loss over the entire outbreak area is described in Table 14. The survey indicates that growth loss and mortality combined account for 1.3% of the total estimated growing stock of budworm-susceptible species. This is somewhat misleading since much of the mortality associated with defoliation is clustered in localized areas. Specific areas may account for considerable growth loss and mortality which, when averaged together with all acres, makes the effects of defoliation appear somewhat negligible.

Table 14.--Comparison of total growth loss and tree mortality per acre to growing stocking on the Wenatchee and Okanogan National Forests.

Strata	Acres	Total growth vol. loss over strata (CF)	Total volume of tree mortality (CF)	Total estimated growing stock vol. (CF) of host species
2	228,770	3,500,181	1,944,545	541,224,066
3	197,020	5,043,712	1,359,438	567,693,428
4	133,640	2,071,420	1,483,404	306,222,696
5	64,490	3,243,847	2,940,744	207,077,390
Total	623,920	13,858,160	7,728,131	1,622,217,580

Top-killing and loss in understory stocking also occurred in localized areas. Averaged over the entire area, budworm-caused top-killing would represent almost 12% of the host trees per acre. This kind of generalization makes top-killing appear more prevalent than it actually is. Where top-killing occurred, it occurred quite heavily and independent of defoliation strata, indicating that it is related more to specific forest conditions or budworm population levels than to the outbreak as a whole.

The clustered distribution of top-killing and mortality suggests that these effects are related more to specific forest stand conditions or to specific intensity of budworm defoliation than to years of defoliation per se. It may be important for future loss assessments to evaluate the forest stand relationships to defoliation. This would provide more meaningful information with respect to specific forest stand response during budworm outbreaks.

SUMMARY

This survey was designed to evaluate budworm-related losses over an entire forest when that forest was stratified by years of recorded defoliation. No attempt was made to evaluate intensity of defoliation or stand conditions within the outbreak.

The survey has indicated that from 1971-1976 over 21 million cubic feet of wood volume was lost through growth rate reductions and tree mortality caused by budworm defoliation. This represents about 1.3% of the total host-growing stock available in the outbreak area.

Average growth rates after 5 years of defoliation were reduced by as much as 22% in true fir and 12% in Douglas-fir. From growth loss, host volume per acre was decreased, in comparison to non-defoliated stands, by an average 10 cubic feet per acre per year in stratum 5. Though, overall, the 5 years of budworm infestation in north-central Washington did not significantly reduce host-growing stock, the accumulated effect of that defoliation upon tree growth, mortality, top-killing, and understory stocking was becoming significant after 5 years. How these effects varied by forest stand type and condition was not investigated. Due to the observed clustered effect of defoliation upon tree mortality and top-killing, it seems likely that defoliation intensity and stand conditions may be more important in assessing losses than years of outbreak, only.

APPENDIX

The effects of budworm defoliation upon radial growth increment were analyzed through the following procedures:

1. Growth increment was divided into 5-year increments (1957-61, 1962-66, 1967-71, 1972-76) by species group. The objective was to use analysis of covariance procedures to arrive at 1972-76 increment means for the defoliated strata which have been adjusted for differences in growth before the outbreak. The adjusted individual tree increment means could then be used in a regression analysis to predict 1972-76 increment growth based upon non-defoliated host tree growth.

2. Results of the analysis of covariance show:

   (a) Adjusted means for the 1972-76 growth increments were significantly different among strata.

   (b) The slopes of the linear regression varied significantly among strata.

   (c) 5-year increment periods 1957-1961 and 1962-1967 had the least contribution (less than 1%) to the variation associated with the regression.

   Since the slopes of the linear regressions varied significantly among strata, the use of analysis of covariance was rejected as a practical method of predicting expected radial increment in the defoliated strata.

3. Simple linear regression analysis was used with the 1967-71 increment as the independent variable and the outbreak years (1972-76), the dependent variable. Each strata was analyzed by species group. For each resulting regression, the null hypothesis was tested for zero intercept. All regressions were consequently forced through zero intercept.

4. The result was to recalculate radial growth (1972-76) of defoliated trees based upon the non-defoliated host tree coefficients for each individual tree. The difference between predicted radial increment and the actual or measured increment represents growth loss.

Comparison of R-square regression values generated in predicting 1972-76 increment growth based upon 3 preceding 5-year increments and 1 preceding 5-year increment.

	5-year increment 1967-71, 1962-66, & 1957-62	5-year increment 1967-71 only	Contribution to regression of 1962-66, 1957-66 increment periods
	R-square	R-square	
Douglas-fir	.9147	.9142	.0005
True fir	.9387	.9382	.0005

Coefficients used in the estimation of expected diameter increment 1972-1976.

	a	b_1	sample size	SE of estimate	R^2
TF	0.0	1.021	97	.031	.9195
DF	0.0	.957	315	.012	.9566

$E = a + b_1A_1$

Height-diameter regression equations developed from sample of non-defoliated data

Species	n		R^2
DF	1605	$H = 20.271 + 4.5938\ D - .036185\ D^2$	.688
F	696	$H = 9.3486 + 5.6279\ D -.045761\ D^2$	.763

REFERENCES

Bousfield, W. E. and G. D. Franc.
1974. Remeasurement of western spruce budworm damage areas on the Clearwater National Forest, Idaho, 1978. USDA, Forest Service, FIDM, Missoula, Mt. Report 79-8.

Carolin, V. M. and W. K. Coulter.
1975. Comparison of western spruce budworm populations and damage on grand fir and Douglas-fir trees. USDA Forest Service Res. Pap., Pac. Northwest Forest Range Exp. Sta. PNW-195. 16 p.

Williams, Carol B., Jr.
1966. Differential effects of the 1944-56 spruce budworm outbreak in eastern Oregon. USDA For. Serv. Res. Pap. Pac. Northwest For. Range Exp. Sta., PNW-33. 16p.

USDA.
1976. USDA Forest Service Environmental Statement. Cooperative western spruce budworm pest management plan. USDA-FS-R6-FES(ADM)-76-7.